Low-Energy (n,γ) Cross Sections Using the Surrogate Technique

Frank S. Dietrich

January 14, 2004

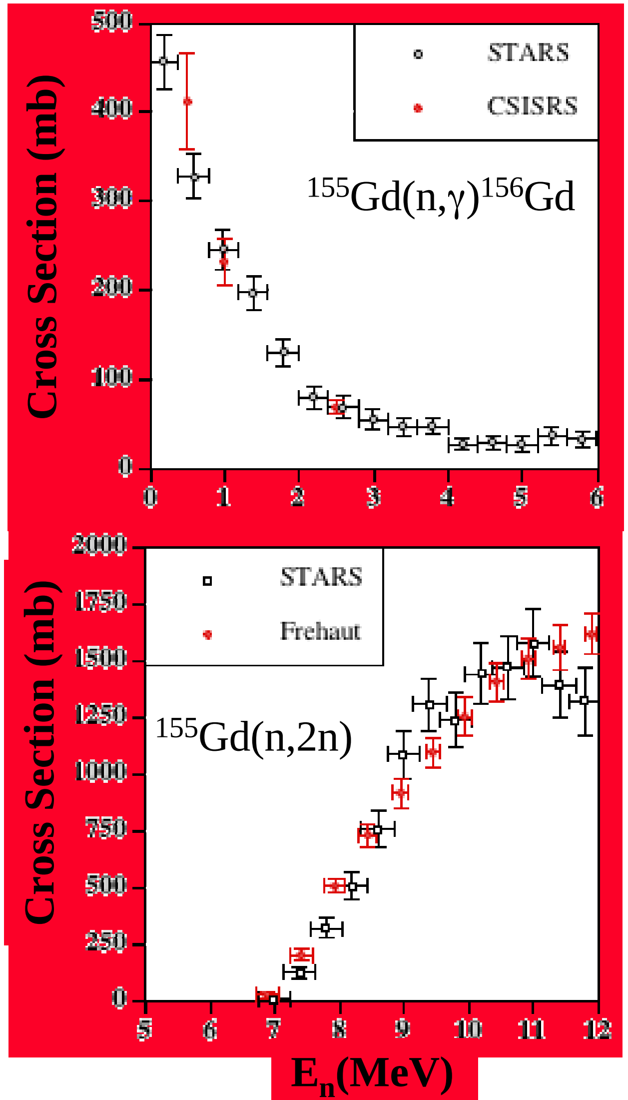
Surrogate technique may be useful for determining important (n,γ) cross sections on unstable nuclei

- **(n,γ) reactions are needed for**
  - *Astrophysical s- and r-processes*
    - Maxwellian averages at ~8 and 30 keV
  - *Stockpile stewardship*
    - Energy range up to ~100 keV particularly important
- **Recent experiment of Bernstein et al. suggests surrogate technique is promising for measuring (n,γ)**
  - *Formed ^{156}Gd compound nucleus in ^{157}Gd(^{3}He,α)*
  - *Measured lowest 2^{+}-0^{+} transition in ^{156}Gd as collector of gamma cascades in coincidence with the alpha particle*
  - *Combining these results with Hoffman's Hauser-Feshbach calculations yield good results with direct experiment for ^{155}Gd(n,γ)*

Bernstein et al. results went down to ~1 MeV neutron energy

Can the technique be extended to lower energies?

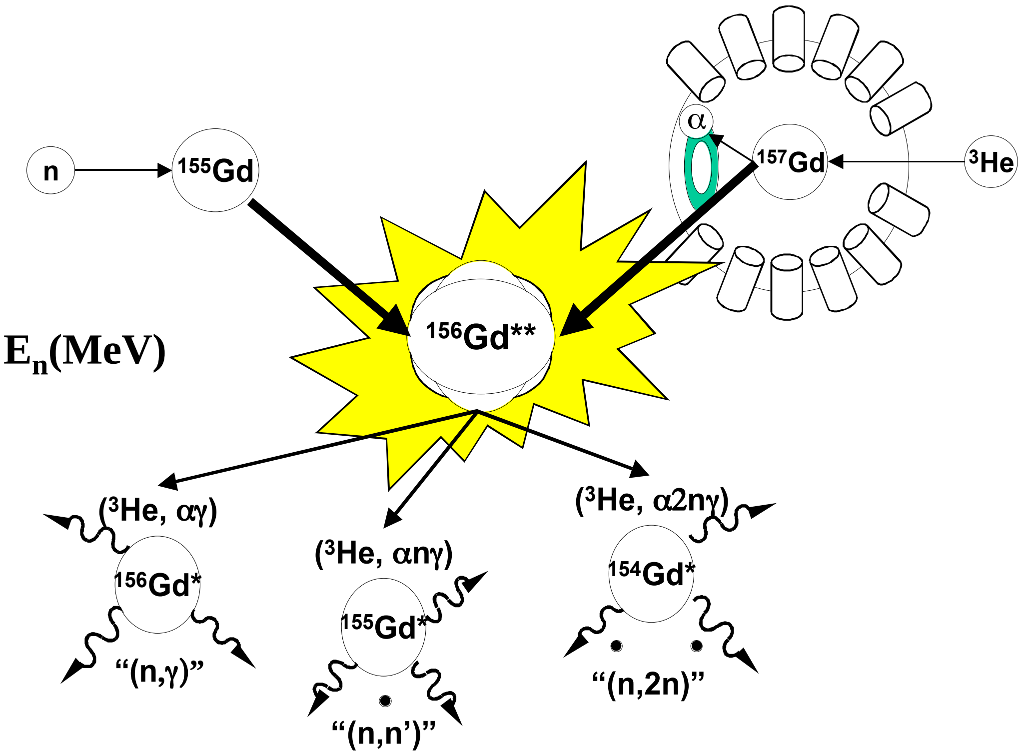
Testing the Surrogate technique



← Surrogate measurement using ^{157}Gd(^{3}He,α)

← Direct measurement

E_n(MeV)



Bernstein *et al.,* analysis in progress

Experiment carried out in Berkeley

The problem, and a suggestion for its solution

In the surrogate technique a compound nucleus must be formed *just above the neutron separation energy* by an alternative reaction (e.g. (p,p'))

Energy of the outgoing charged particle tags the energy of the compound nucleus, but is uncertain by ~25-100 keV

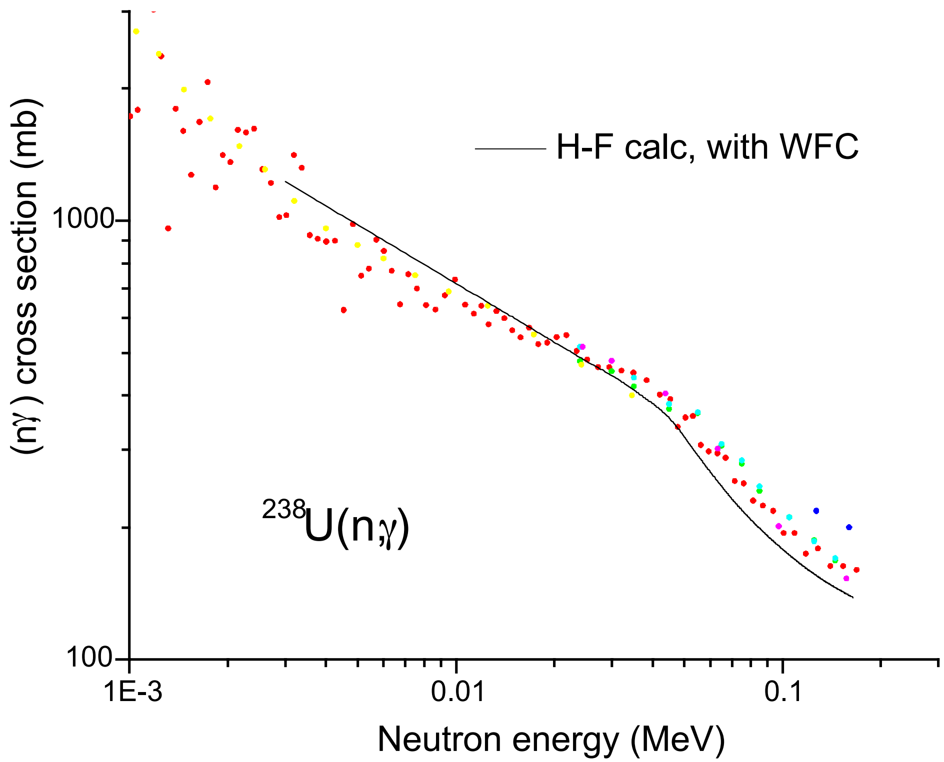
This yields a corresponding uncertainty in the simulated neutron energy, which is comparable to the desired *entire neutron energy range*

SUGGESTION:

- **Measure at somewhat higher equivalent neutron energies (100-200 keV) with well characterized detector resolution**
- **Assume nuclear models calculate shape adequately, use measurement to normalize the overall scale**

How well should this work? We are starting with some tests of (n,γ) calculations on nonfissile actinides

(n,γ) shape determined mainly by s-, p- wave transmission coefficients and inelastic thresholds



At 10keV, T_1/T_0 ~ 1/20

***BUT* contributions to capture are equal!**

Can see this from

$$\sigma_l \sim \frac{T_l\, T^{\gamma}}{T_l + T^{\gamma}}$$

Conclusion: optical model has to get both T_0 and T_1 right at low energies

S-wave strength functions determined from resonance studies are equivalent to T_0 at low energies

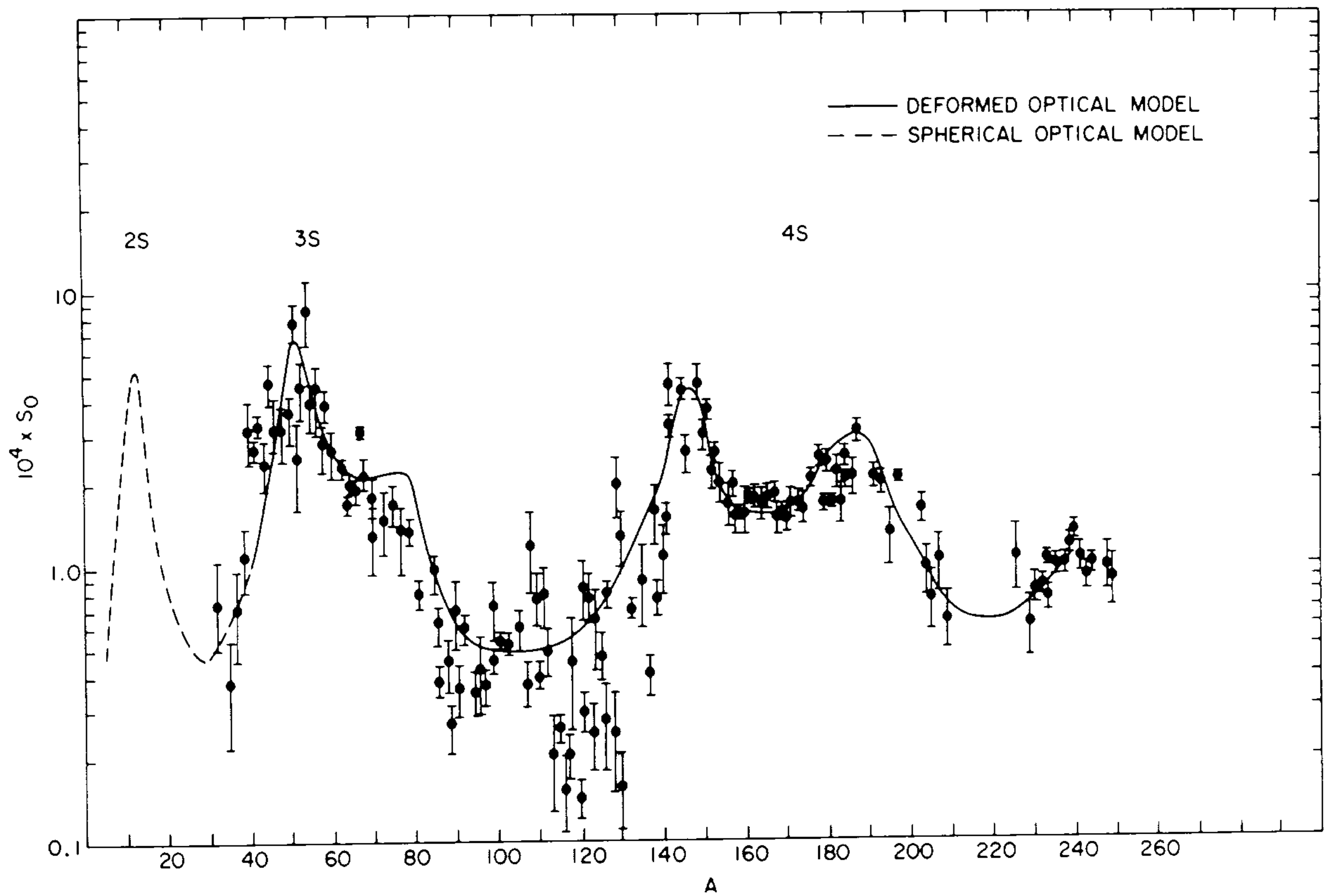


Figure 3. Comparison of experimental and theoretical values of the s-wave neutron strength function. The solid and dashed curves represent deformed and spherical optical model calculations respectively. See the caption of Figure 1 for the optical model parameters.

P-wave strength function, equivalent to T_1 at low energy, is "out of phase" with S-wave

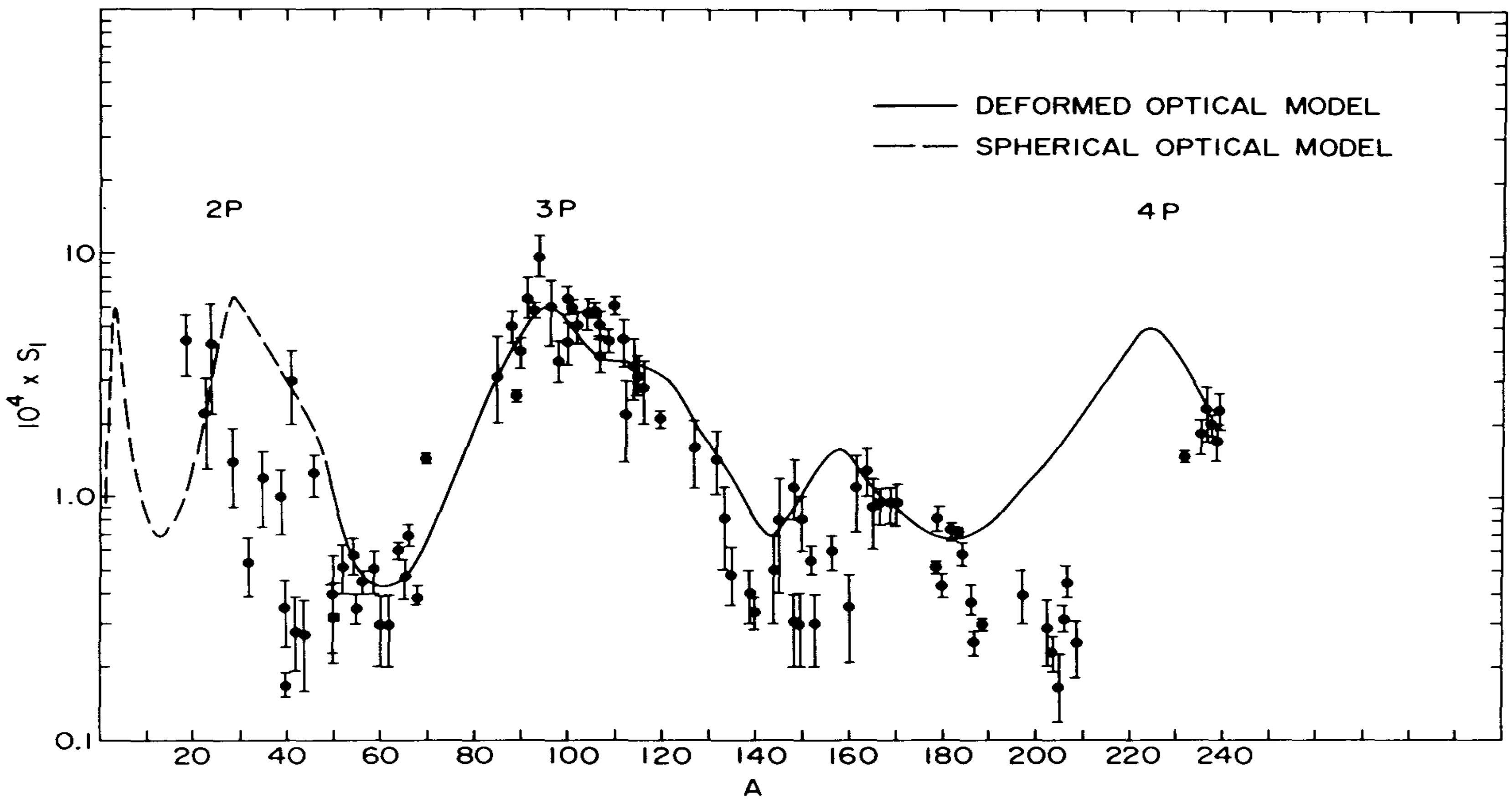
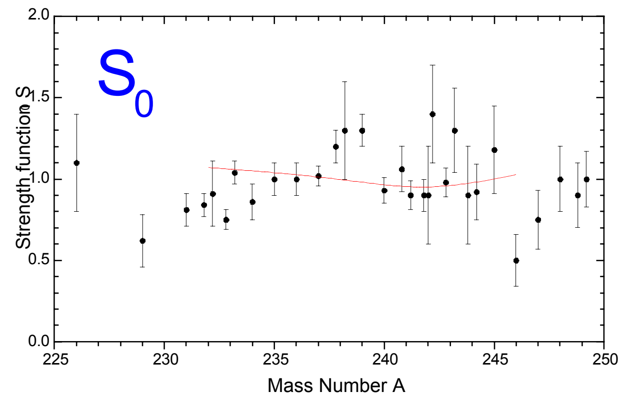


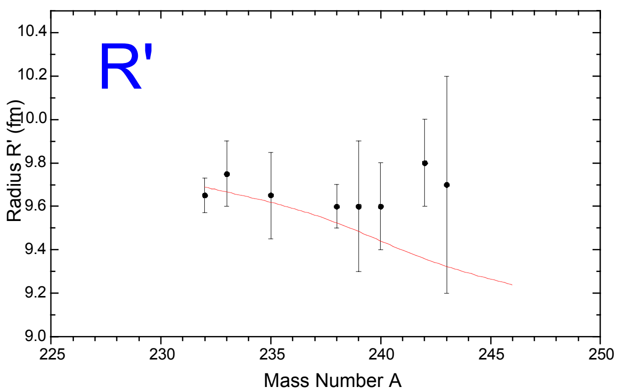
Figure 4. Comparison of experimental and theoretical values of the p-wave neutron strength function. The solid and dased curves represent deformed and spherical optical model calculations respectively. The small peak at A = 160 is due to the rotational splittting of the 4p-giant resonance as prdicted by Buck and Perey[47]. For details, see the text.

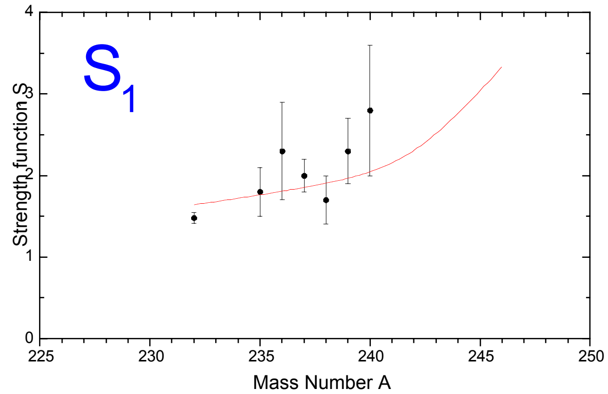
Optical model for actinide study was carefully fit to regional strength function information

Coupled-channel calculation

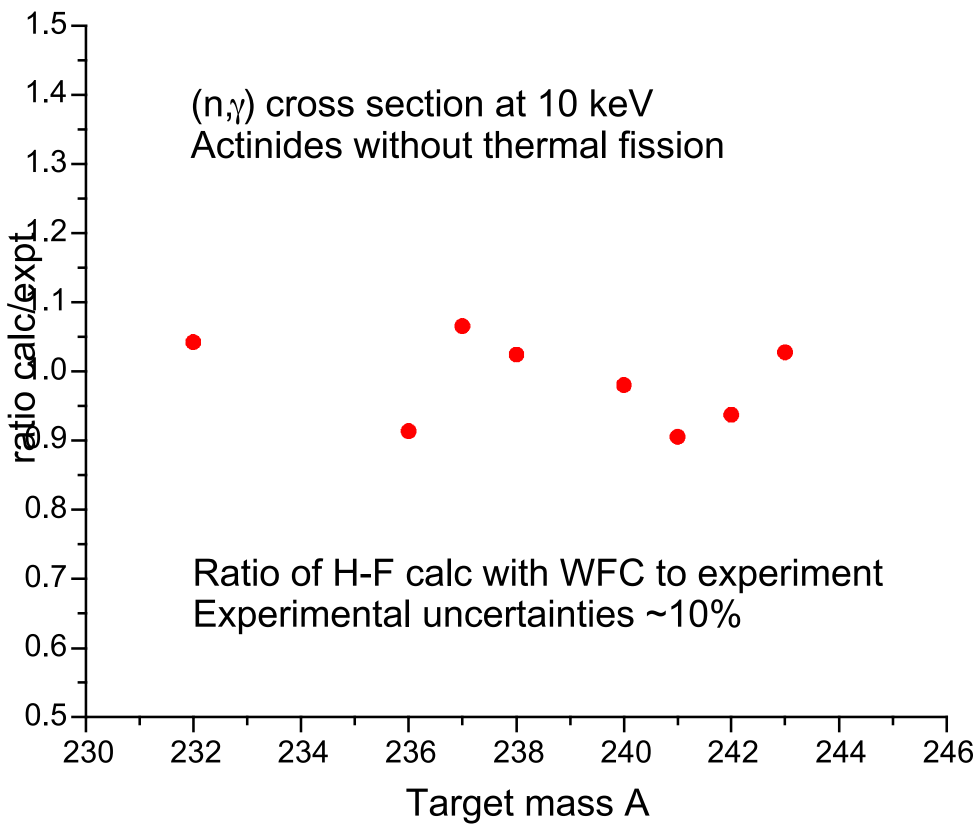
Low-energy parameters help fix strength and geometry of potential at low energies







Regional potential yields consistent results for known stable, nonfissile actinide targets



We are currently extending these results to fissile nuclei

These use Walid Younes's calculated fission probabilities for ^{235}U, ^{241}Pu

Conclusions

Normalizing a 10-100 keV (n,γ) calculation with a surrogate reaction at higher energies requires a good regional optical model giving reliable T_0 and T_1

Strength-function data available only for stable nuclei, so technique can't be extrapolated reliably very far from valley of stability

Angular-momentum mismatch is most severe for (n,γ). Therefore, alter JΠ distribution in the surrogate reaction by

- Changing the surrogate reaction, *e.g*. (p,p') vs. (^{3}He,α)
- Use wide range of angles for outgoing particle, since $\Delta J \sim qR$